The Interaction of Nonlinear Internal Waves with Other Processes

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Award Number: N00014-05-1-0285
http://maelstrom.seos.uvic.ca/

LONG-TERM GOALS

To understand and parameterize small-scale ocean processes.

To understand the physical oceanography of straits and semi-enclosed seas.

OBJECTIVES

To clarify and understand the dimensionless parameter space of internal tide generation.

To elucidate and quantify the back effect on internal waves, and other motions, of refracted and breaking surface waves.

APPROACH

Recent studies have been largely analytical, with support from numerical evaluation.

WORK COMPLETED

A study of the Fourier representation of quadratic friction **u|u|**, where **u** is the two-dimensional vector current, has been completed.

As part of a review of internal tide generation in the deep ocean, the non-dimensional parameter space has been described and the flow regimes in different parts of this space have been discussed and clarified.

The use of the hydrostatic approximation in internal tide generation theory has been evaluated and an error in an earlier formulation has been corrected.

Some progress has been made in adding dissipation to studies of the interaction between surface waves and currents.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE **The Interaction of Nonlinear Internal Waves with Other Processes**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Victoria,Department of Physics and Astronomy,PO Box 3055,Victoria, B.C. V8W 3P6,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

RESULTS

A classic result is that, if a rectilinear tidal current is composed of two constituents of different frequencies, with one constituent much smaller than the other, then the weaker constituent experiences proportionately 50% more friction than the stronger constituent. Results for an arbitrary amplitude ratio have only been obtained in the past by expansion in the ratio of current constituent amplitudes, assumed small, or by numerical simulation. We derive closed form solutions for this problem and for many extensions to allow for several constituents and for two-dimensional currents. The work is a consolidation, clarification, and extension of many scattered studies. Figure 1 shows the scaled amplitude of the Fourier coefficients of u|u|, for a rectilinear tidal current with two constituents, as a function of the ratio of current constituent amplitudes.

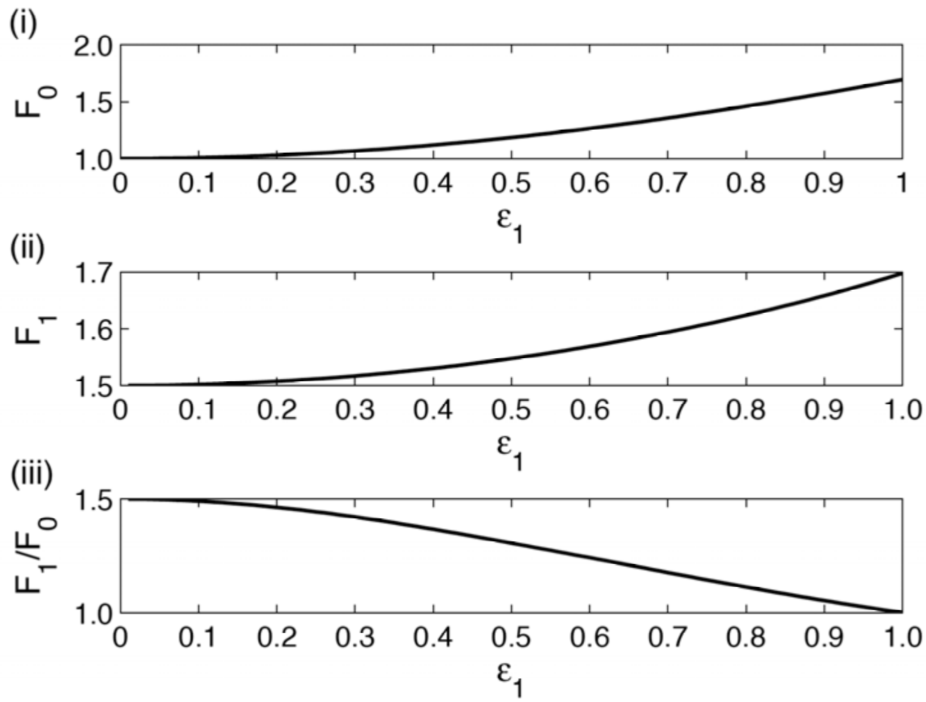

Figure 1. The scaled amplitudes of the Fourier coefficients of u|u| for a rectilinear current, as a function of the ratio of current constituent amplitudes. The top panel applies to the main constituent, the second panel to the weaker constituent, and the bottom panel shows the ratio of friction coefficients.

Figure 1 shows that both current constituents feel more friction as a consequence of the presence of the other. The weaker constituent feels proportionately 50% more friction when the ratio of current constituent amplitudes is small, but the difference disappears as the ratio approaches 1.

In a review of internal tide generation in the deep sea, an attempt has been made to consolidate different regimes in the dimensionless parameter space (Figure 2) defined by a steepness parameter, taken as the ratio of a typical bottom steepness to the slope of internal tide rays, and an excursion parameter, given by the ratio of the barotropic tidal excursion to the typical horizontal scale of the topography.

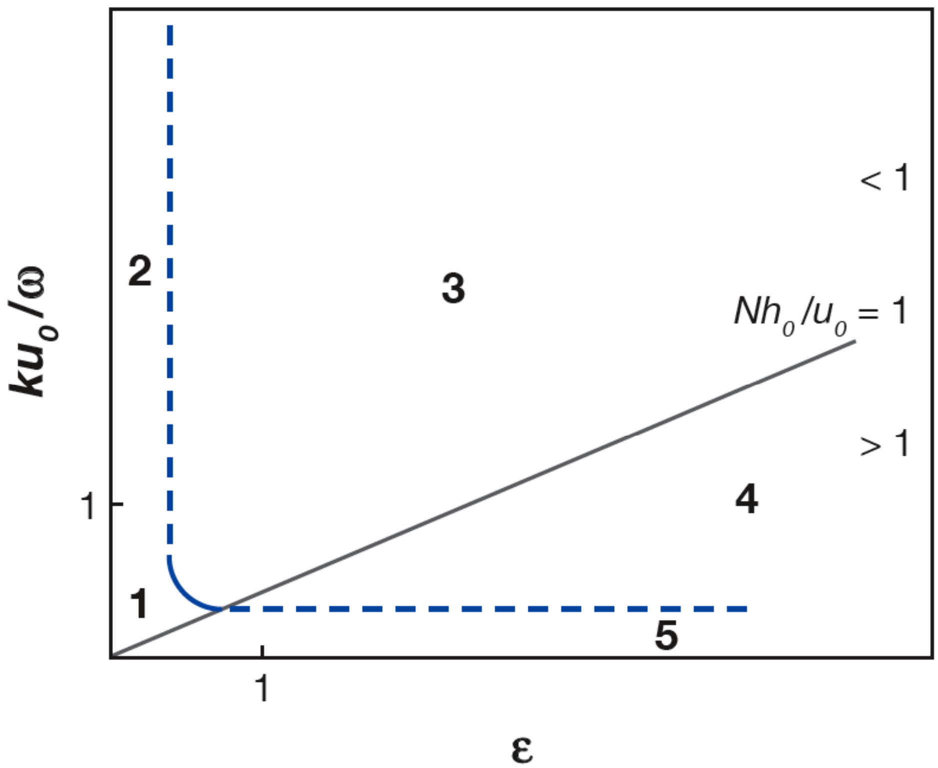

Figure 2. The nondimensional parameter space describing internal tide generation in the deep ocean. The x-axis is the steepness parameter, taken as the ratio of a typical bottom steepness to the slope of internal tide rays. The y-axis is the excursion parameter, given by the ratio of the barotropic tidal excursion to the typical horizontal scale of the topography.

Classic linear internal tide generation applies in regime one, with both parameters small. In region 2, with large excursion but small steepness, linear theory can still be used, but multiple frequency harmonics appear, describing reinforced lee waves. By contrast, region 5, with small excursion but finite steepness, has motions only at the forcing frequency, but with spatial harmonics of the wavenumber of the bottom topography and singularities when the steepness is one. Regions 3 and 4 have finite values of both parameters but solutions for steady flows provide guidance. In region 3 a stratification parameter is small and linear dynamics apply, whereas nonlinear hydraulic responses can appear in region 4 with stronger stratification.

A comparison of different formulations of internal tide generation theory has led to the realization that it is not appropriate to assume that the forcing barotropic tide can be assumed hydrostatic but the resulting internal tide non-hydrostatic. Physically, if non-hydrostatic terms matter for the baroclinic response, then the propagating part of the solution has short scales for which it cannot be assumed that the generating barotropic tide is hydrostatic.

Some progress has been made in understanding the back effect of dissipating surface waves on the underlying mean flow, with the realisation that the physics of adiabatic interactions is sufficiently clear that extension to allow for dissipative changes in the wave field is simple. Further study will attempt to elucidate the implications for nonlinear internal waves.

IMPACT/APPLICATIONS

The results on Fourier decomposition of u|u| will aid frequency-domain models of tides in shallow seas.

Clarification of the parameter space of internal tide generation will help to organize further studies.

Clarification of hydrostatic/non-hydrostatic formulations of internal tide generation theory strengthens the foundations of the field.

RELATED PROJECTS

The projects described above have also been supported by Canadian funding agencies. A related project supported entirely by Canadian agencies concerns breaking surface waves, and we are also embarking on a study of "unexpected" waves in Gaussian seas, with the argument that a large wave after a calm period can be of greater concern than an extreme wave which is not much larger than those preceding it.

PUBLICATIONS

Dewey, R. K., D. L. Richmond, and C. Garrett. 2005. Stratified tidal flow over a bump. *J. Phys. Oceanogr.* 35, 1911-1927. [published, refereed]

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HONORS/AWARDS/PRIZES

Elected Foreign Associate of the National Academy of Sciences, 2006.